Cumulative and Synergistic Effects of Physical, Biological, and Acoustic Signals on Marine Mammal Habitat Use

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LONG-TERM GOALS

The long-term goal of this research effort is to enhance the understanding of how variability in physical, biological, and acoustic signals impact marine mammal prey and resulting marine mammal habitat use. This is especially critical in areas like the Bering Sea where global climate change can lead to rapid changes of the entire ecosystem. The Arctic is projected to experience "ice-free" summers within 30 years (Wang and Overland, 2009). This will have significant impacts for the natural ecosystem dynamics and human use associated with transportation, fishing, military activity, and energy exploration. Shifts in plankton community structure are a likely response to large-scale changes in ice cover. Zooplankton population dynamics are a dominant component of the ecosystem that provide the crucial trophic link between primary production and Federally-protected species such as marine mammals. Understanding the relationship between ice cover and zooplankton community structure in different regions of the Bering Sea will provide information for predicting upper-level trophic dynamics, including marine mammal distribution and range, as sub-Arctic conditions continue to change. Baseline measurements will play an important role in mitigation efforts and environmental assessments as commercial and military activity increases in the region.

OBJECTIVES

The main goal of this year's effort was to relate acoustic backscatter characteristics associated with estimates of zooplankton/neckton abundance, spatial and temporal variability, dominant size class, and taxa to marine mammal detection patterns on the central and southeastern Bering Sea shelf. The first objective examines bio-physical interactions influencing the dynamics of marine mammal zooplankton and fish prey. The second objective relates the prey variability to observed patterns of marine mammal vocal detections indicative of animal presence and habitat use.

Objective 1: What effect do changing sea ice dynamics have on zooplankton populations?

a) How does zooplankton size and community structure vary with sea ice mediated changes in bloom timing?

b) What are the differences in plankton dynamics between a winter with ice (2010) and without ice (2009) in the southeastern Bering Sea?

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Objective 2: Do zooplankton dynamics under ice correspond to quantifiable marine mammal patterns?

a) Is zooplankton community structure during the winter and spring a predictor of marine mammal habitat use in the summer and fall?

b) Are detections of ice-associated marine mammals related to zooplankton dynamics during the winter and spring?

Effort in FY2011 was focused on analysis of acoustic data from 2 mooring sites in 2008-2011 and integration of the acoustic data with the physical oceanographic data obtained from other sensors on the NOAA Pacific Marine Environmental Laboratory (PMEL) EcoFOCI moorings. The integration of acoustic, satellite, and oceanographic information has provided insight on potential prey patterns corresponding to marine mammal presence and vocal behavior. Full ecosystem monitoring provides the relevant context for interpreting marine mammal vocal detection patterns and identifying the combination of factors most strongly associated with marine mammal presence and habitat use in this area.

APPROACH

Active and passive acoustic measurements at two sites on the eastern Bering Sea shelf (known as M2 and M5 through the EcoFOCI Program (Stabeno and Hunt, 2002)) commenced under ONR Research Award N00014-08-1-0391 in September 2008. Continuous data collection is currently underway at both sites M2 (southern region) and M5 (central region) through September 2011. The focus of this year's work was to enhance the understanding of biological scattering dynamics and how it relates to marine mammals across the Bering Sea shelf. Efforts focused on the scattering dynamics of zooplankton and micronekton by investigating 1) interactions at the ice-water interface, 2) shifts in community structure associated with ice and other physical ocean characteristics, and 3) timing and community structure of seasonal vertical migrations.

Acoustic backscatter associated with temporal and vertical spatial distribution of zooplankton in the water column is measured with echosounders of three different frequencies (125, 200, and 460 kHz). By recording acoustic backscatter at three frequencies, the differences in backscatter between the frequencies can be used to distinguish between different scatterers in the water column (Watkins & Brierley, 2002). The following broad taxonomic categories: small mesozooplankton (e.g. copepods), medium mesozooplankton (e.g. chaetognaths), large mesozooplankton (e.g. euphausiids), and swim-bladdered fish will be distinguished. The data also supports the calculation of estimates of in situ numerical densities of animals assuming single taxa aggregations (Lawson et al., 2004; Warren et al., 2003). This multi-frequency backscatter approach has been used successfully in the South Shetland Islands, Antarctica for several years (i.e. Seasonal Reports for 2000-2006 http://swfsc.noaa.gov/textblock.aspx?Division=AERD&id=3154&ParentMenuId=42) to provide estimates of krill biomass and spatial and temporal distribution and variability. Vertical and oblique net tows are conducted to collect zooplankton at each mooring site during the mooring maintenance cruises. Tows are done over different depth intervals to discern if there are differences in the composition of the zooplankton vertically and during night and day to measure diel changes. Large (> 1 m^2) and small (0.25 m^2) mouth nets are used as are different mesh sizes (333 µm, 64 µm) to capture both large and small zooplankton.

The cornerstone of success is the appropriate time series analyses and comparisons over time at a single location and between locations. While there is great scientific merit in quantifying the relationship between acoustically-detected physical and biological parameters of the marine ecosystem, the integration of the acoustic datasets with ancillary data will further enhance the value of the research by ensuring the appropriate comparisons are made between locations and over time at the same location. Yearly time series of currents from ADCP measurements, temperature, salinity, and fluorescence are being made concurrently from instruments on the mooring at each location. The physical oceanography moorings have been collecting data for over a decade at each site and are deployed within 1km of the acoustic mooring. Ocean fluorescence is indicative of phytoplankton concentration and provides the crucial link between observations of physical parameters and observed patterns of higher trophic level taxa. Time series of ice cover thickness and percent cover in the North Pacific and Arctic are publically available from Ice Desk of the National Weather Service (US Dept of Commerce, NOAA). Integrating ancillary data relating to phytoplankton, current, and sea ice with the physical and biological parameters obtained by the acoustic sensors has the potential to illuminate relationships presently uninvestigated during the winter season due to severe weather conditions and the presence of ice.

WORK COMPLETED

A project planning meeting focused on the active acoustic data analysis was held in State College, PA and attended by J. Miksis-Olds, S. Denes, S. Parks, and J. Warren in April 2011.

<u>Data Collection</u>

Mooring cruises took place in Sept/Oct 2010 and Apr/May 2011. Data was successfully downloaded at both moorings during each cruise, and all instruments were fully operational. All M2 and M5 instruments were refurbished and re-deployed. Final data retrieval from instruments at M2 and M5 is scheduled for September 2011.

Zooplankton net tows were conducted at and around the moorings to identify dominant species, species composition, and numerical density during mooring deployments and recoveries, as well as on separate research cruises in the area. Samples obtained closest in time to a targeted temporary ice retreat and closest in proximity to the mooring location were four zooplankton samples collected from April 8-9, 2009 by Alexei Pinchuk at the University of Alaska Fairbanks. These samples were collected between 10 and 75 miles from the mooring location. Small zooplankters were sampled with a 25-cm diameter CalVET system (CalCOFI Vertical Egg Tow; Smith et al., 1985) having 0.15 mm mesh nets. Each net was equipped with General Oceanics flowmeters in the mouth of the net to monitor the volume filtered. The flowmeters were attached to the net frame with an elastic cord to keep the flowmeter inside the nets during descent. The nets were fished vertically during the day from 100m depth to the surface or from the bottom to the surface at depths less than 100m. It was not possible to conduct oblique tows during this period due to the presence of ice and the operating characteristics of the research vessel.

<u>Data Analysis</u>

To assess patterns and variability of physical and biological parameters in different regions of the water column, the water column was divided into horizontal layers based on depth: surface (0-10 m), upper water column (11-30 m), lower water column (30-45 m), and epibenthos (45-70 m). The AWCP data were processed in 2 m vertical depth bins within each of the water column regions. Mean volume backscatter coefficient (mean s_v in units m^2/m^3) was calculated from integrations in 24 hour bins over

each 2 m depth layer and from identified region subsets within individual aggregations using EchoView software (Myriax, Tasmania). The visually identified aggregations were then classified as to the likely source of the scattering based on differences in scattering amplitude between the three frequencies.

Theoretical scattering curves for four different types of individual scatterers were generated and dB-differences at the three acoustic frequencies used in this study were calculated. Scattering amplitudes (and the subsequent dB differences at 125, 200, and 460 kHz) were generated using a Stochastic Distorted Wave Born Approximation model (Demer and Conti, 2003) for the following scatterers: 1) small scatterers such as copepods (lengths of 1 – 5 mm), 2) medium scatterers (lengths of 5 – 15 mm) which includes juvenile krill, chaetognaths, and amphipods, 3) large scatterers consisting of adult euphausiids (lengths of 15 - 30 mm), 4) resonant scatterers, and 5) unknown. The acoustic system was not able to detect the weak scattering strengths of scatterers less than approximately 5mm unless they were present in extremely dense aggregations. Neretic copepod species typically found over the middle shelf (*Pseudocalanus* spp., *Acartia longiremis, Oithona* spp. and *Calanus*) are less than 5mm (Gardner and Szabo, 1982; Coyle and Pinchuk, 2002) and comprised the small scatterer category. The resonant scatterer type represents an organism with a gas-inclusion such as a swim-bladdered fish or siphonophores which has a strong resonant peak in the scattering spectra (Stanton, 1998). Two theoretical resonant scattering spectra were generated: weak (<3 dB increase in S_v at 200 kHz) and strong (>20 dB increase in S_v at 200 kHz). Aggregations were classified as belonging to one of the five categories (small, medium, or large scatterer, resonant, or unknown) by determining the shortest geometric distance between the three dB differences calculated for the aggregation and that of the theoretical scatterers. If the closest geometric distance was more than 16 dB (an arbitrarily chosen value), then the aggregation was classified as unknown.

Periodicity of acoustic backscatter patterns was assessed with an autocorrelation technique. Mean volume backscatter values were calculated for 2 minute periods (corresponding to the bi-hourly sampling duration) over 4 meter depth increments offset from the surface. This resulted in 15 depth layers and 48 samples per day. The data were linearized and grouped into periods of 14 days for analysis. Each 14 day period was zero-meaned and normalized. Zero-meaning shifts the mean from an arbitrary positive value to zero; values that were all positive now oscillate around zero. Normalizing prevents bias due to increased volume backscatter not associated with periodicity. The autocorrelation value with a 24 hour lag was computed for each 14 day period. This value represents the relatedness of the mean volume backscatter to the successive 24 hour period. These 24 hour lag correlation values can then plotted by depth and time. The resulting plot can be used to identify regions of increased 24 hour periodicity as a function of time and depth.

Ongoing detection and classification of marine mammal vocalization from the PAL data is providing a time series of vocal detections by known species for comparison to the prey data.

RESULTS

Results stemming from this year's efforts highlight 1) the integration of the multiple datasets to acoustic measurements and provide context for interpreting marine mammal vocal activity, and 2) scattering categorization of zooplankton and fish over time at individual mooring locations. Data integration was concentrated over a short period of time surrounding the temporary, 2- week retreat of seasonal ice over the M5 mooring in March 2009. The approach used in integrating information from

multiple datasets over this time period is now being applied to the larger time series acquired between 2008 and 2011.

Hydrographic data confirmed the acoustic signal associated with changing surface ice conditions (Figure 1), and the combined information from the biophysical mooring sensors revealed changes in winter trophic level dynamics during a temporary ice retreat at M5 that would have otherwise been undetected by traditional ship-based observations (Figure 2). Changes in the acoustic environment, zooplankton dynamics, and acoustic detection of marine mammals were observed amidst a physically stable and uniform water column with no indication of a phytoplankton bloom (Figure 2C). Analysis of acoustic backscatter periodicity, intensity, and acoustic signatures revealed an increase in scattering abundance and diel vertical migration during the retreat period (Figure 2D and 3). A comparison of scattering aggregation acoustic signatures with theoretical models showed that the water column was dominated by medium sized (5-15mm) scatters (Figure 4) before, during, and after the retreat. Information from net tows suggest that the medium scatterers detected in the acoustic record were from chaetognaths and Calanus (Figure 5). These data demonstrate the value of acoustic technologies to monitor changing ecosystems dynamics in remote and hazardous locations.

The vocal presence of ice breeding pinnipeds and bowhead whales was detected over the course of the winter 2009 season (Figure 6). During the ice retreat, bowhead whales and walrus vocalizations continued to be detected, while bearded and ribbon seal detections were absent. It is not known if the ice seals left the area in conjunction with the ice, or whether they remained in the area and did not engage in vocal mating displays. Biomass of prey did increase in the area during the temporary retreat, and the cessation of ice breeding pinniped vocalizations may reflect a shift in activity from breeding to feeding during this time. When the ice returned after the rapid retreat, bearded seals were detected almost immediately, whereas ribbon seal vocalizations were not regularly detected again until the ice was thicker than 20 inches (Figure 4). This suggests that ice utilization by ice seals is species dependent and related to specific characteristics of the ice.

IMPACT/APPLICATIONS

The acoustic measurement system used in this project has the advantage of being deployed for long periods of time on subsurface moorings, affording the opportunity to collect valuable data during the harshest conditions of the winter season when traditional sampling techniques are not possible. The combination of acoustic and environmental datasets revealed that there is a rapid ecosystem response to relatively short-term change in ice cover, which has a profound effect on zooplankton abundance in the deeper water column and marine mammal vocal activity. Identifying relationships between physical forcing mechanisms, biological activity, and marine mammal habitat use will not only be critical in understanding and ultimately predicting how marine mammals respond to noise, but also to how ecosystems respond to variability on multiple time scales.

The system used in this study is appropriate for use in almost all marine environments. It provides an advantage over continuous recording instruments in that the initial real-time processing of environmental sound by the PALs detects and identifies sources of interest without an overwhelming amount of data needing post-processing. The PALs and active acoustic sensors can be programmed to sample at the same time scale to ensure synoptic data collection. The adaptive sub-sampling protocol of the PAL is flexible and can incorporate a wide range of detection algorithms.

It is highly likely that the acoustic environment of the Bering Sea and Arctic regions in general will be altered as the area experiences climate changes. The Bering Sea has already experienced significant warming (~3°C) over the last several decades which has been closely associated with a marked decrease in sea ice concentration, duration, and maximum extent over the area (Stabeno et al. 2007; Wang and Overland 2009). Direct climate effects will be linked to ice coverage, and indirect acoustic effects will occur as humans begin to use areas previously inaccessible due to ice. How this will impact the diverse sub-Arctic marine mammal species is unknown, but extreme care should be taken in interpreting the confounding effects of sound on animals in this area as their entire ecosystem will be in a state of flux.

TRANSITIONS

This project represents a transition from the acoustic (both passive and active) detection and characterization of specific sound sources and scattering targets to the study of ecosystem acoustics and ecosystem response to environmental change. Ecosystem monitoring is especially critical in Arctic and sub-Arctic regions because as climate change impacts these regions, natural ecosystem response will be a confounding factor for any study investigating the impacts of human activity on marine organisms.

RELATED PROJECTS

Acoustic backscatter measurements from the AWCP instruments will be integrated with ship and satellite measurements of phytoplankton species composition, size structure, and productivity to understand the potential consequences on zooplankton populations measured from moored acoustical observations in a NASA ROSES funded project.

REFERENCES

Coyle, K.O., Pinchuk, A.I., 2002. Climate-related differences in zooplankton density and growth on the inner shelf of the southeastern Bering Sea. Progress in Oceanography 55, 177-194.

Demer, D.A., Conti, S.G., 2003. Validation of the stochastic distorted-wave Born approximation model with broad bandwidth total target strength measurements of Antarctic krill. ICES Journal of Marine Science 60, 625-635.

Gardner, G.A., Szabo, I., 1982. British Columbia pelagic marine Copepoda: An identification manual and annotated bibliography. Canadian Special Publication of Fisheries Aquatic Sciences 62, 536 p.

Lawson, G. L., P.H. Weibe, C.J. Ashjian, S.M. Gallager, C. S. Davis, and J.D. Warren. 2004. Acoustically-inferred zooplankton distribution in relation to hydrography west of the Antarctic peninsula. Deep-Sea Res Part II 51, 2041-2072.

Smith, P.E., Flerx, W., Hewitt, R.P., 1985. The CalCOFI vertical egg tow (CalVET) net. In: Lasker, R. (Ed.), An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the northern anchovy Engraulis Mordax. NOAA Technical Report NMFS 36, U.S. Department of Commerce, pp. 23-33.

Stabeno, PJ, Bond, NA, Salo, SA. (2007). On the recent warming of the southeastern Bering Sea shelf. Deep Sea Research Part II 54, 23–26.

Stabeno, PJ and Hunt, GL Jr. (2002): Overview of the Inner Front and Southeast Bering Sea carrying capacity programs. Deep-Sea Research 49(26), 6157–6168.

Wang, M and Overland, JE. (2009). A sea ice free Arctic within 30 years? *Geophysical Research Letters* 36: L07502.

Warren J. D., Stanton, T.K., Wiebe, P.H., Seim, H.E., 2003. Inference of biological and physical parameters in an internal wave using multiple-frequency, acoustic-scattering data. ICES Journal of Marine Science 60, 1033-1046.

Watkins, J. L., Brierley, A.S., 2002. Verification of acoustic techniques used to identify and size Antarctic krill. ICES Journal of Marine Science 59**,** 1326-1336.

PUBLICATIONS

Nystuen, JA, Miksis-Olds, JL, Stabeno, PJ (in prep). Soundscapes under sea ice. Journal of the Acoustical Society of America.

Miksis-Olds, JL, Stabeno, PJ, Napp, JM, Pinchuk, A, Nystuen, JA, Warren, JD, Denes, SL. (submitted) Ecosystem response to a temporary sea ice retreat in the Bering Sea. Progress in Oceanography.

Van Opzeeland, IC, Miksis-Olds, JL (accepted, in press, invited submission). Acoustic ecology of pinnipeds in polar habitats. In Aquatic Animals: Biology, Habitats, and Threats. Nova Science Publishers. [refereed]

Miksis-Olds, JL, Parks, SE (accepted, in press). Seasonal trends in acoustic detection of ribbon seals (*Histriophoca fasciata*) in the Bering Sea. Aquatic Mammals. [refereed]

Miksis-Olds, JL, Nystuen, JA, Parks, SE. (2010). Detecting Marine Mammals with an Adaptive Sub-Sampling Recorder in the Bering Sea. Journal of Applied Acoustics 71: 1087-1092. DOI:10.1016/j.apacoust.2010.05.010. [refereed]

PRESENTATIONS

Miksis-Olds, JL, Denes, SL, Nystuen, JA (2011). Ecosystem monitoring: providing the proper context for interpreting behavioral responses of marine mammals.” 4th Interngovernmetnal conference: The Effects of Sounds in the Ocean on Marine Mammals. Amsterdam, The Netherlands, 5-9 September.

Denes, SL, Miksis-Olds, JL, Nystuen, JA, Mellinger, DK (2011) A comparison of marine mammal detections from co-located sub-sampling passive acoustic monitors. Fifth International Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals using Passive Acoustics, Mt. Hood, OR, 21-25 August.

Miksis-Olds, JL, Parks, SE (2011). Ribbon seal (*Phoca Histriophoca fasciata*) vocalizations in the Bering Sea. Acoustic Communication by Animals, Third International Symposium, Ithaca, NY, 1-5 August.

Miksis-Olds, JL, Warren, JD (2011). Characterizing biological scatter before, during, and after a temporary ice retreat in the Bering Sea. Journal of the Acoustical Society of America 129: 2401.

Miksis-Olds, JL, Nystuen, JA (2010). Factors influencing biodiversity and marine mammal habitat use in the Bering Sea. Journal of the Acoustical Society of America 127: 1758.

Miksis-Olds, JL, Nystuen, JA, Parks, SE (2010). What does ecosystem acoustics reveal about marine mammals in the Bering Sea? The Second International Conference:The Effects of Noise on Aquatic Life. Cork, Ireland. August 16-20.

Nystuen, JA, Miksis-Olds, JL (2010). Soundscapes under sea ice:Can we listen for open water? European Conference on Underwater Acoustics. Istanbul, Turkey. July 5-9.

Nystuen, JA, Miksis-Olds, JL (2010). Soundscapes under sea ice:Can we listen for open water? Acoustical Society of America, Baltimore, MD. April 19-23.

Miksis-Olds, JL, Nystuen, JA (2010). Acoustic tracking of upper trophic level dynamics in the Bering Sea. 2101 Ocean Sciences Meeting. Portland, OR. February 22-26.

Miksis-Olds, JL, Parks, SE, Nystuen, JA (2009). Understanding the relationship between marine mammals and their environment in the Bering Sea. Journal of the Acoustical Society of America 126: 2271.

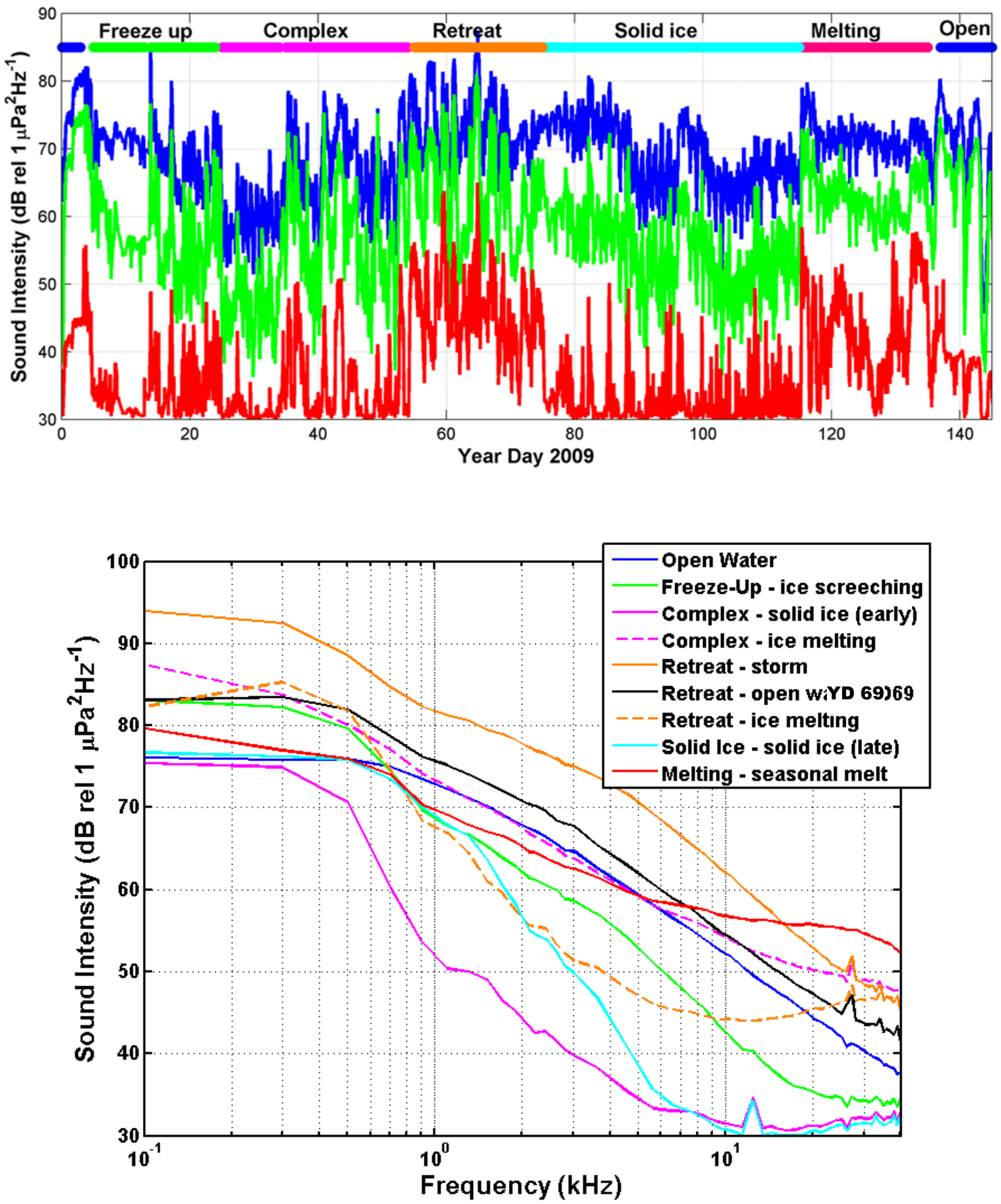

Figure 1. (A) Time series of sound levels at 800 Hz (blue), 2000 Hz (green) and 30,000 Hz (red) during the winter ice season at mooring location M5. Open water and five periods of ice conditions are indicated with color bars running along the top of the figure. The color of each surface category is coordinated with representative spectra identified during the associated periods in (B).

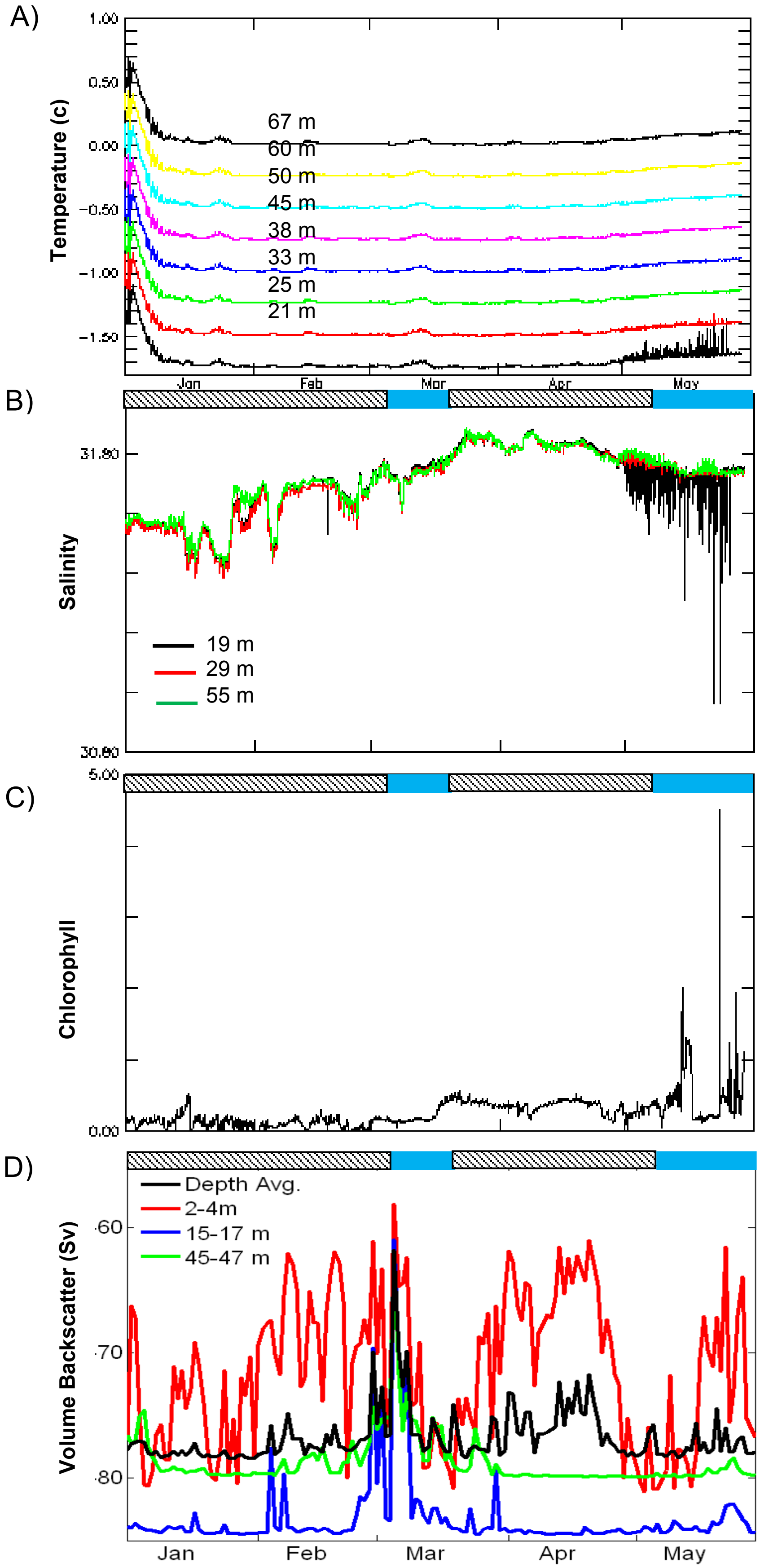
A)
1.00
0.50
0.00
-0.50
-1.00
-1.50
Temperature (c)
67 m
60 m
50 m
45 m
38 m
33 m
25 m
21 m
Jan
Feb
Mar
Apr
May
B)
31.80
30.80
Salinity
19 m
29 m
55 m
C)
5.00
0.00
Chlorophyll
D)
Depth Avg.
2-4m
15-17 m
45-47 m
-60
-70
-80
Volume Backscatter (Sv)
Jan
Feb
Mar
Apr
May

Figure 2. Time series of temperature (A), salinity (B), estimated chlorophyll concentration at 20 m (C), and 460 kHz volume backscatter (D) from January –May 2009. There is a 0.5 C offset between the temperature time series at each depth. Temperature, salinity, estimated chlorophyll, and volume backscatter values represent daily averages The horizontal bar running across the top of each panel indicates periods of open water (solid blue) and ice cover (black and white striped).

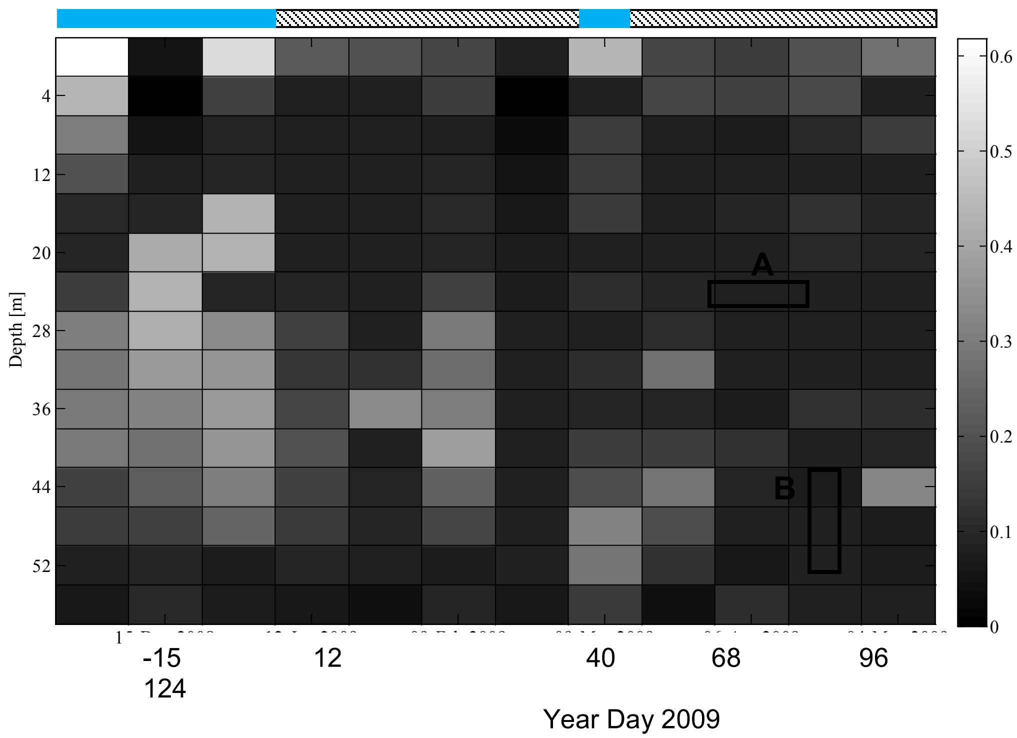

Figure 3. Correlogram of 460 kHz acoustic backscatter. Autocorrelation values for 14 day segments integrated over 4m depth bins. Lighter values on the colorbar indicate greater periodicity. Negative Year Day values indicate days prior to 2009. The horizontal bar running across the top of the figure indicates periods of open water (solid blue) and ice cover (black and white striped).

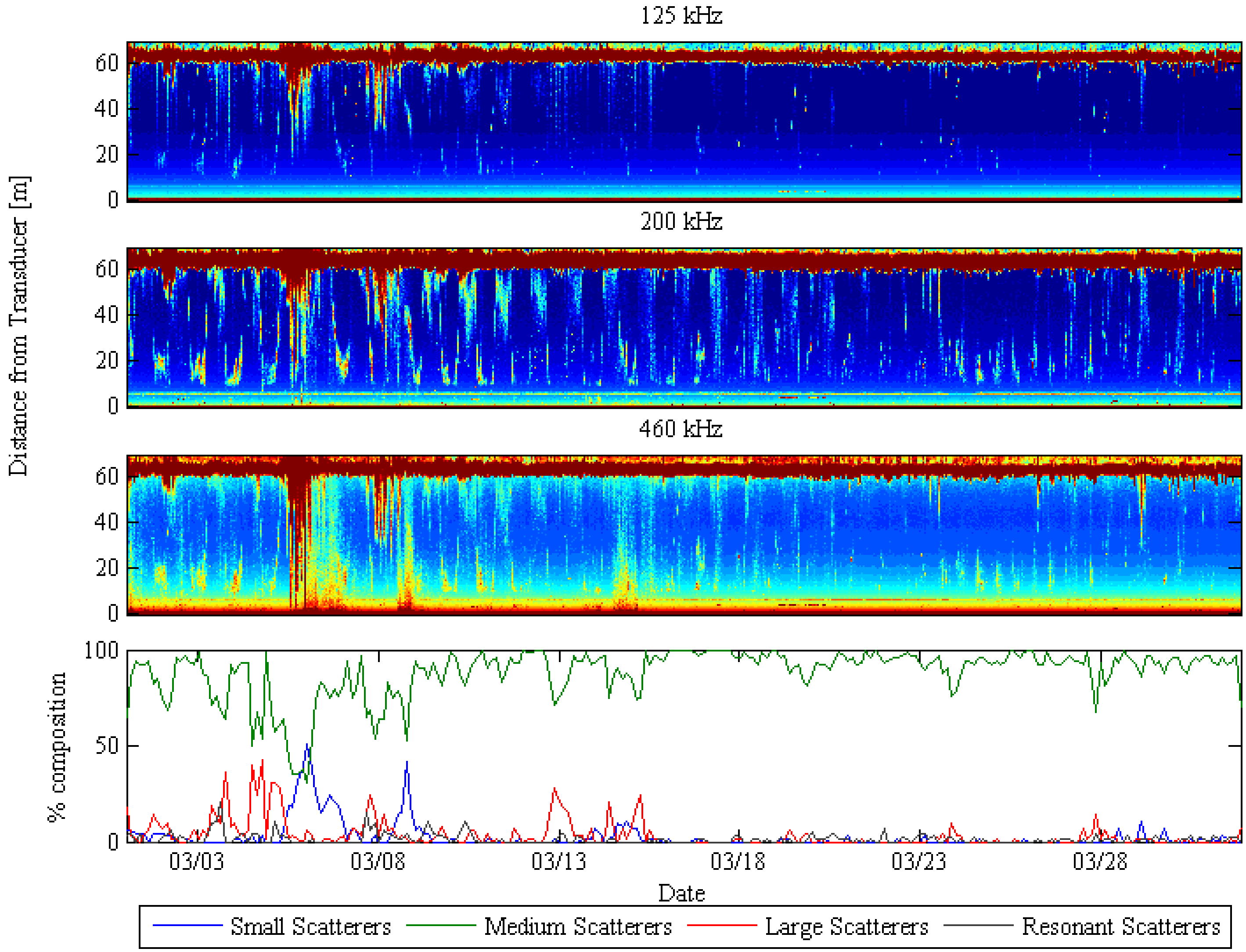

Figure 4. Month long echograms at three frequencies are time aligned with the scattering categroization at mooring location M5. The % composition was calcualted from daily volume backscatter averages over the full depth of the watercolumn.

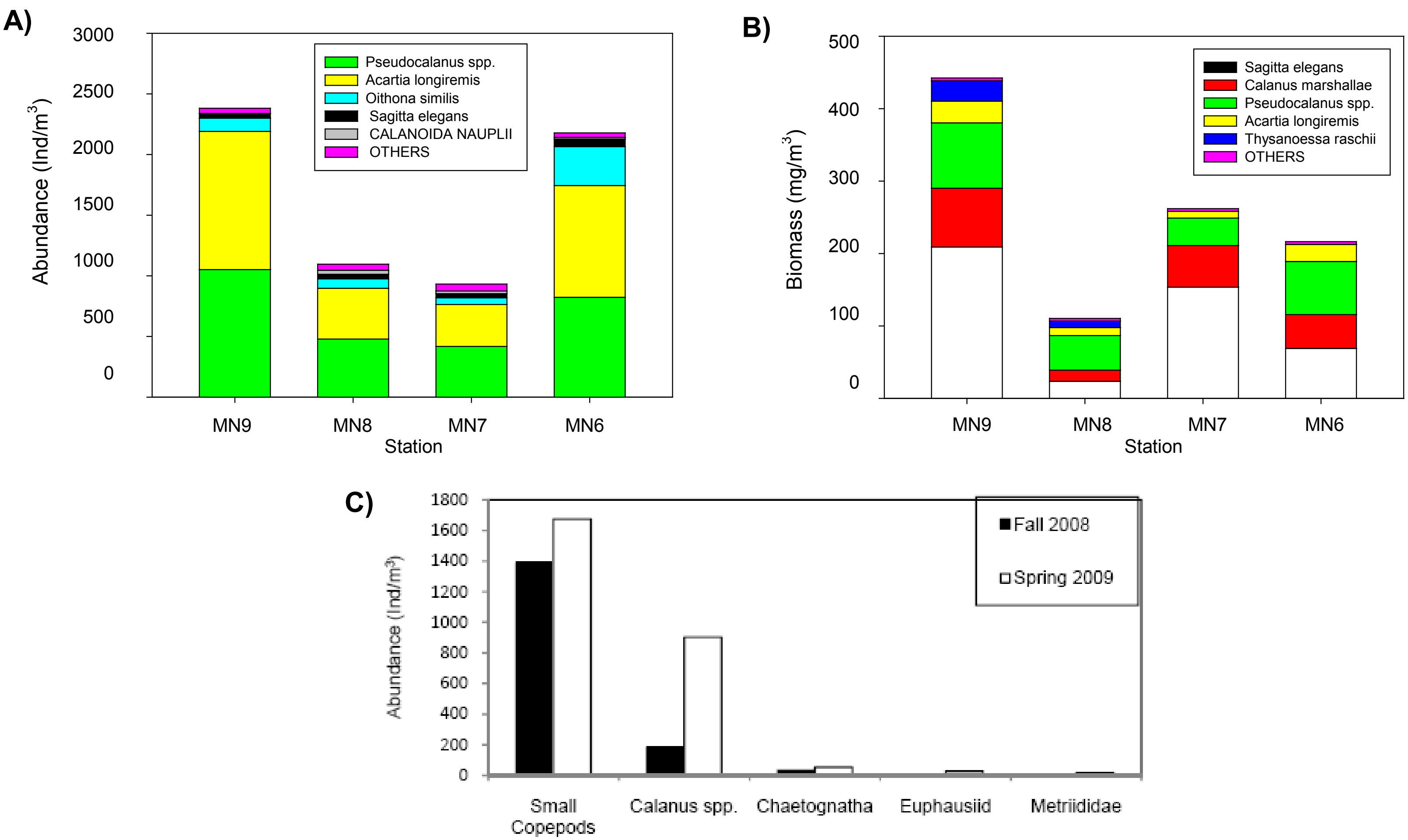

Figure 5. (A) In April 2009 CalVET samples, small neritic copepods Pseudocalanus spp. and Acartia longiremis were most abundant near the mooring site. However the biomass of the zooplankton community (B) was dominated by cheatognats Sagitta elegans and by Calanus. While euphausiids Thysoanoessa raschii were present in the samples, limitations of our sampling gear did not support estimates their abundance/biomass quantitatively. (C) Abundance estimates from bongo tows prior to and following the seasonal ice presence. Small copepods included Pseudocalanus spp., Acartia longiremis, and Oithona spp.

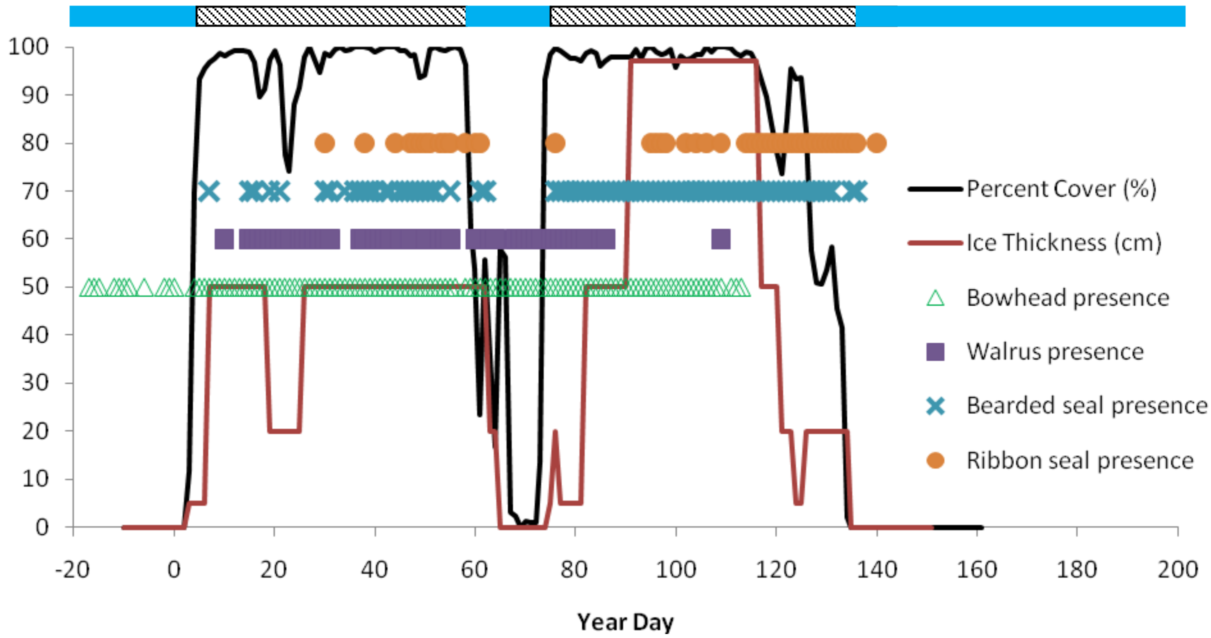

Figure 6. Time series of ice presence over the M5 mooring during the 2008-2009 winter season. Negative Year Day values represent days prior to 2009. A temporary ice retreat was observed in March 2009 (YD 60-90) which persisted for approximately two weeks. Acoustic presence of species does not correspond to a numerical value on the y axes. The species specific symbols reflect daily acoustic presence and are separated spatially for easy visualization. The horizontal bar running across the top indicates periods of open water (solid blue) and ice cover (black and white striped).